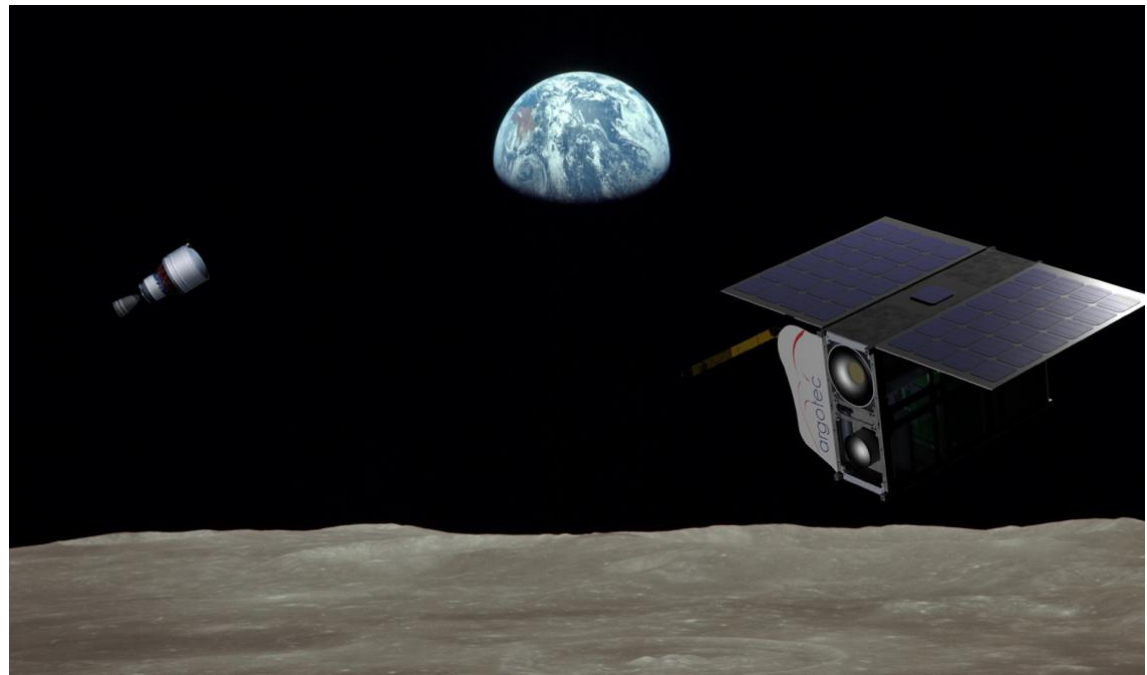
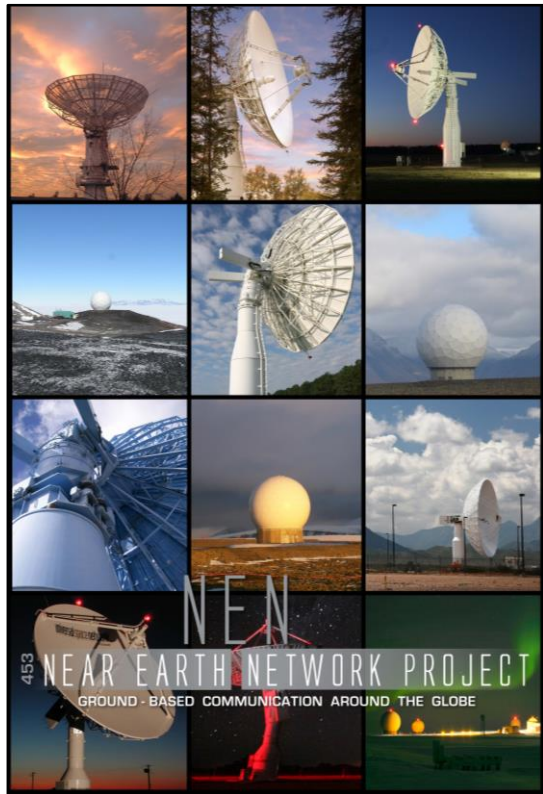




NASA Near Earth Network (NEN) Support for Lunar and L1/L2 CubeSats

Scott Schaire
April 2017



The European Space Agency (ESA) ArgoMoon, is one of 13 CubeSats to be launched with the Space Launch System (SLS) for the Exploration Mission 1 (EM-1) scheduled for February 2019.

Agenda



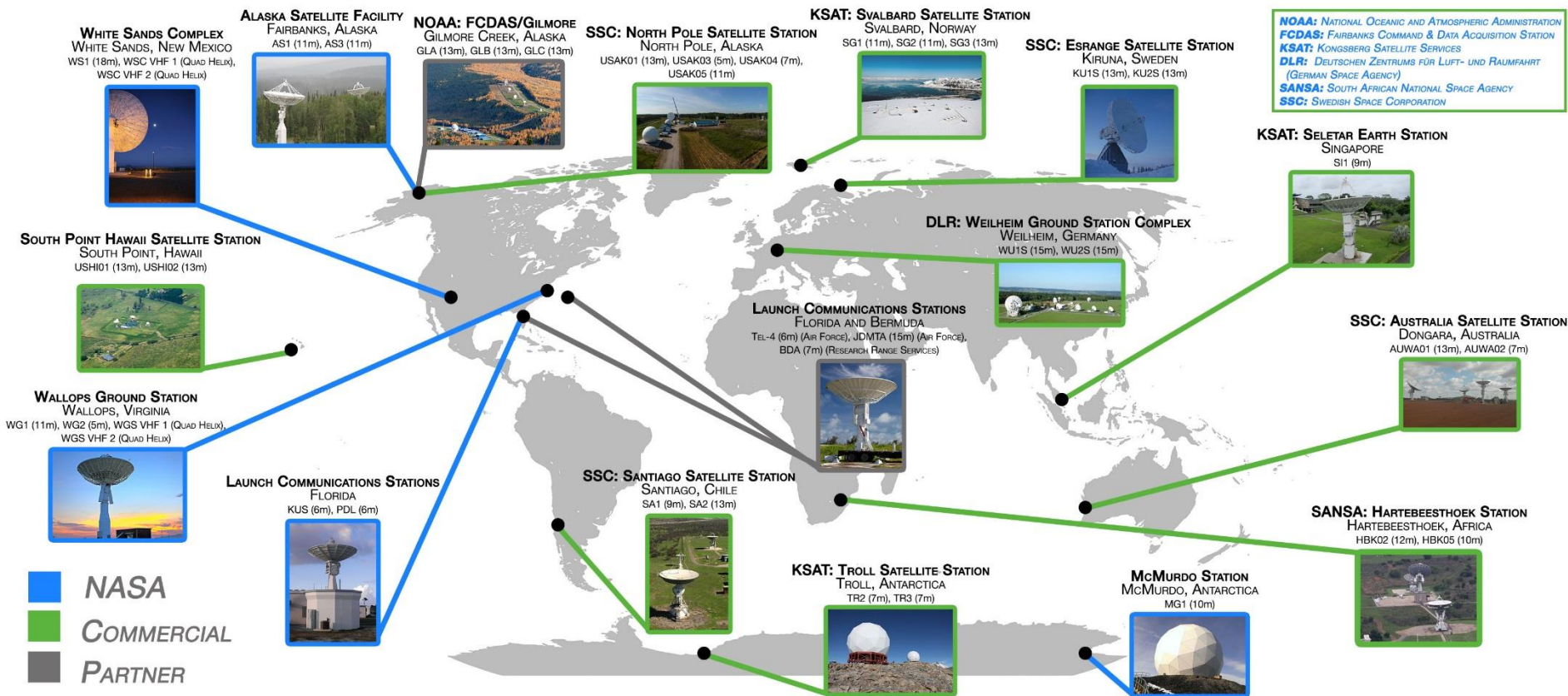
- Overview
- Upcoming CubeSat Support for NEN
- NEN Lunar/L1/L2 CubeSat Support
- NEN Evolution
- Conclusion

Near Earth Network Overview



- **As shown on the following slide, the NASA Near Earth Network (NEN) is composed of stations distributed throughout the world**
- **NEN services**
 - NASA-owned and operated ground stations
 - Partner agencies (e.g., National Oceanic and Atmospheric Administration (NOAA) Command and Data Acquisition (CDA))
 - Commercial ground station providers (e.g., Kongsberg Satellite Services (KSAT), Swedish Space Corporation (SSC) and its subsidiaries, Deutsches Zentrum für Luft- und Raumfahrt (DLR))
- **The NEN supports orbits in the Near Earth region from Earth to 2 million kilometers**
 - Communication services are provided for various low-Earth orbits (LEO), geosynchronous orbits (GEO), highly elliptical orbits (HEO), LaGrange orbits, lunar and suborbital, and launch trajectories

THE NEAR EARTH NETWORK PROJECT



JUNE 2016

SCHEDULING



The Near Earth Network (NEN) is comprised of tracking stations distributed throughout the world in locations as shown on this map.

The NEN provides Telemetry, Tracking, and Commanding (TT&C) and ranging services to a extensive and diverse customer base, which includes approximately 40 missions - from the high-rate Earth Observing System (EOS) missions such as Aqua, Aura, SMAP, AIM, EO-1, GPM, GRACE, DSCOVR, and OCO-2, to Small Explorer (SMEX) missions including IRIS and HESSI.

PRE-MISSION TESTING



It also provides TT&C services for an average of about 150 passes per day. Commercial stations such as Kongsberg Satellite (KSAT) Svalbard Ground Station (SGS) in Norway and SSC/USN Alaska Ground Station in North Pole, Alaska provide almost half of the 150 passes per day collectively.

PRE-MISSION PLANNING & ANALYSIS



- Space communications at Goddard and Wallops goes back to the beginning days of NASA.
- GSFC software and hardware engineers in the 80's and 90's conceived and were responsible for what is today the NASA NEN 10 meter and 11 meter ground stations at Wallops, Alaska, and McMurdo.
- Today, GSFC is fortunate to continue its leadership role for the Near Earth Network.
- The Near Earth Network (NEN) supports about 40 NASA and other agency satellites.

GLOBAL NETWORK MONITORING, CONTROL & COORDINATION



- The NEN collects about 1,500,000,000,000 science bytes/day, which is the equivalent of 100 two-hour DVD quality movies/day.
- Today the NEN average data rate is 100 million bits/sec and the highest satellite downlink rate is 300 million bits/sec from the Lunar Reconnaissance Orbiter.
- Future satellite data rates are expected to be an order of magnitude greater, four thousand million bits/sec.
- The NEN constantly strives to reduce costs, improve the reliability of data transmission, and meet new and evolving mission requirements.

QUICK FACTS:

ABOUT:

NEN Frequencies and Bandwidths for NTIA Licensing



Band	Function	Frequency Band (MHz)	Bandwidth (MHz)	Maximum Bandwidth per Transmitter (MHz)
S Uplink	Earth to Space	2025-2110	85	Typically <5
X Uplink	Earth to Space	7190-7235 (Two NEN sites to 7200)	10	Typically <5
S Downlink	Space to Earth	2200-2290	90	5
X Downlink	Space to Earth, Earth Exploration	8025-8400	375	375
X Downlink	Space to Earth, Space Research	8450-8500	50	10
Ka Downlink	Space to Earth	25500 – 27000	1500	1500

Near Earth Network (NEN) Upcoming CubeSat Support



Mission	Launch Date (No Earlier Than)
CPOD/PONSFD (A and B)	TBD
SOCON 1	2017
MicroMAS (A and B)	2017
Jefferson High	2017
CryoCube	2018
iSAT	2018
SOCON 2	2018
Lunar IceCube	2019
ArgoMoon	2019
BioSentinel	2019
CuPiD	2019
Burst Cube	2019
RadSat	2019
TROPICS (9 CubeSats)	2020
CUTIE	2021
CSIM	TBD
Propulsion Pathfinder (RASCAL)	TBD
Kit Cube	TBD
PIC/USIP	TBD

NEN Potential Benefits for EM CubeSats



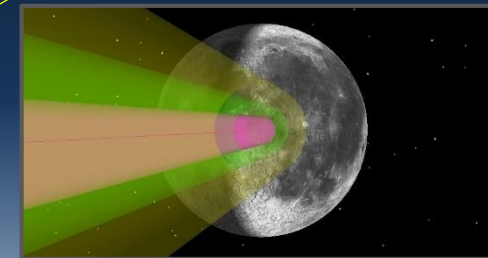
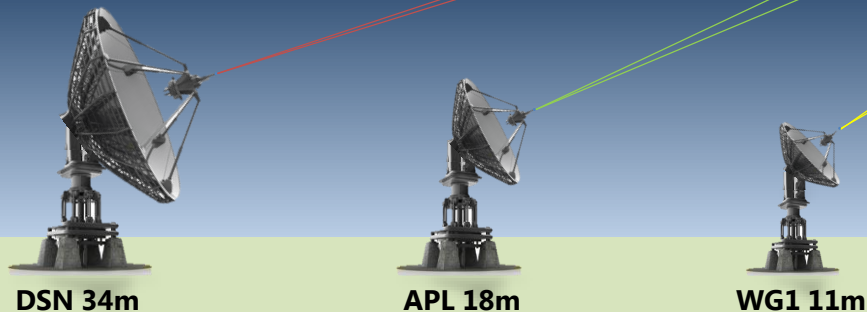
NEN offers “as-is” and upgradable ground system solutions for lunar, L1/L2, and future exploration CubeSat missions that could benefit the EM-1 CubeSat missions

- **The NEN may benefit EM-1 CubeSat missions utilizing the IRIS radio in the form of coverage and larger beamwidth**
 - NEN ground systems are positioned around the globe and are able to provide significant to full coverage, depending on sites utilized, for CubeSats in Lunar orbit or beyond (e.g., L1/L2 missions)
 - NEN coverage could be utilized to provide higher data rate support to EM-1 CubeSat missions immediately following dispersal from Orion (~35,000 km through 100,000km)
 - Smaller NEN apertures (e.g., 11m), compared to other apertures, provide a larger beamwidth, which can benefit CubeSat missions in the event of navigation/ephemeris uncertainty
 - DSN, can provide complete coverage to lunar CubeSats; however, the NEN, if upgraded, could provide supplemental support to close gaps and provide backup coverage during single DSN coverage times
 - NEN could also be utilized during periods of time when DSN has coverage, but are unable to support any one particular CubeSat due to other commitments (e.g., to another of the nine EM-1 CubeSats being supported by DSN)

NEN Beamwidth Advantage for Lunar EM-1 CubeSats



- **The NEN's use of small apertures provides a larger beamwidth, compared to the larger DSN apertures, which can benefit Lunar CubeSats with uncertain ephemeris data**
 - WG1 11m would cover 3.10x the area of a DSN 34m
 - APL 18m would cover 1.86x the area of a DSN 34m (NEN looking at obtaining services from APL)
- **Assumptions:**
 - Frequency: 8450 MHz
 - The Moon's angular diameter is 0.5 degrees
- **3 dB Beamwidth for Varying Antenna Diameter***
 - 10m = 0.250 degrees (half of Moon angular diameter)
 - 11m = 0.226 degrees
 - 13m = 0.191 degrees
 - 18m = 0.136 degrees
 - 34m = 0.073 degrees



3D View

* Not all antenna diameters depicted in graphic

NEN Achievable Data Rates with Representative EM CubeSat Missions (Based on Analysis)



- **NEN would be in a position to support a majority of the discrete IRIS radio downlink rates assuming the NEN implements the upgrade to ensure IRIS downlink compatibility**
 - The IRIS radio does not support a continuous range of data rates, but rather discrete rates (not all possible rates have been tested/verified)
- **Notes/Considerations:**
 - Morehead without cryogenic LNAs was not shown since Morehead is planning to upgrade the asset

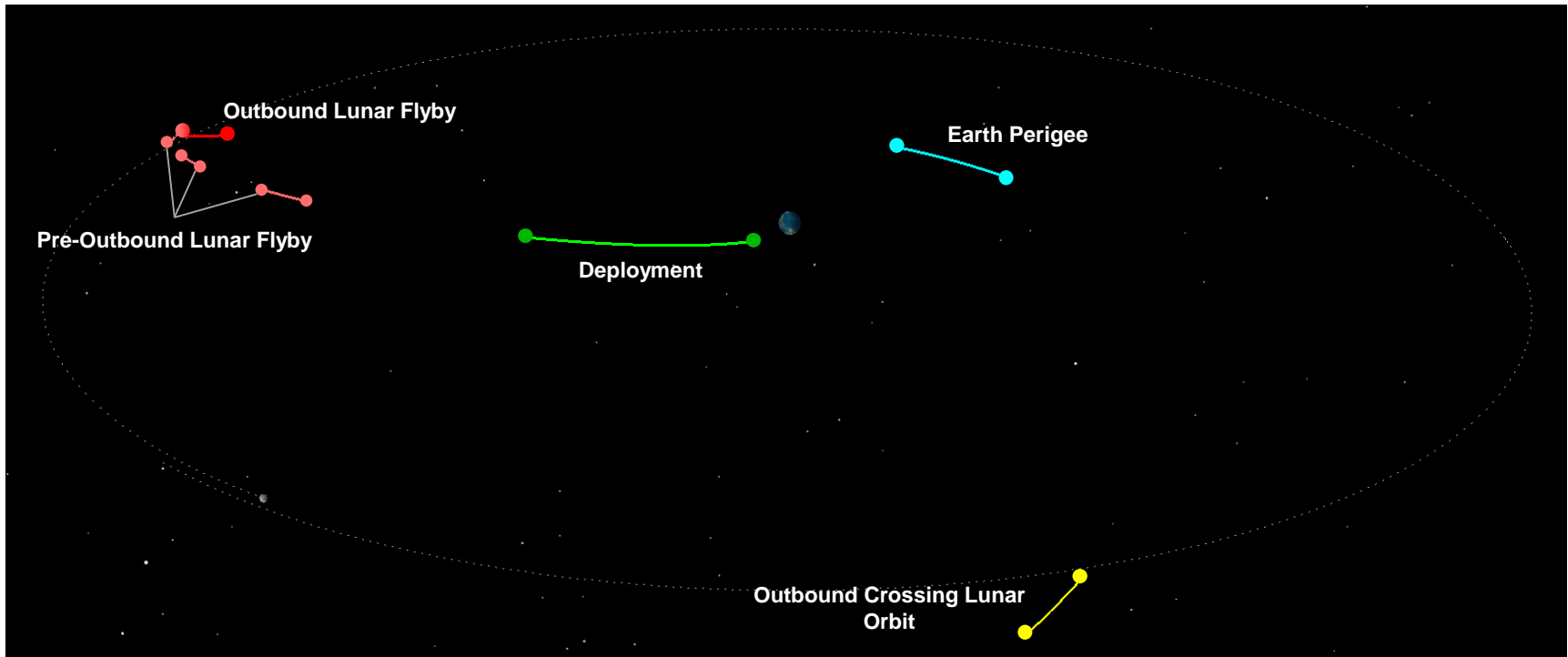
- **CubeSat Radio/Antenna Assumptions:**
 - Frequency: 8.45 GHz
 - Modulation = BPSK
 - COTS CubeSat radio: PA output power of 4W
 - COTS antenna with 11 dBi gain @X-band
 - Passive loss of 1 dB
- **General Assumptions:**
 - Achievable rates assume a 1.3 dB margin
 - Slant range of 405,221 km (Max Lunar Distance)
 - 10 degrees elevation
 - Link availability for propagation effects : 99%

Asset Size	Reference Antenna	Cryogenic LNAs	G/T ¹ (dB/K)	Conv. ½ ² Rates kbps	Turbo 1/6 Rates kbps	NEN Asset Capable of Supporting IRIS Discrete Data Rates (kbps)							
						1	4	8	16	32	64	128	256
11m	WG1	No	30.74	18.7	50.8	✓	✓	✓	✓	✓	✗	✗	✗
		Yes	31.64	23.0	62.5	✓	✓	✓	✓	✓	✗	✗	✗
13m	SSC Hawaii/Australia	No	33.32	37.0	100.5	✓	✓	✓	✓	✓	✓	✗	✗
		Yes	34.22	45.5	123.6	✓	✓	✓	✓	✓	✓	✗	✗
18m	APL	No	34.15	41.0	111.4	✓	✓	✓	✓	✓	✓	✗	✗
		Yes	35.05	50.4	137.1	✓	✓	✓	✓	✓	✓	✓	✗
21m	Morehead	No	NA	-	-	-	-	-	-	-	-	-	-
		Yes	38.15	105.4	237.5	✓	✓	✓	✓	✓	✓	✓	✗

¹ Includes a Lunar noise effect of 2.9 dB (WG1) and 3.767 dB (SSC). Morehead and APL Lunar Noise effects are approximate.

² Capabilities are currently untested with the IRIS radio.

Lunar IceCube Pre-Lunar Capture/Orbit Events

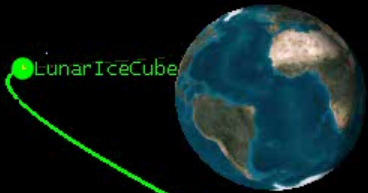


Color	Event	Start Time	Stop Time	Dur. (min)	Distance (km)	Data Rate	NEN Stations with Coverage of Event
Green	Deployment	7 Oct 2018 15:39	8 Oct 2018 03:52	733	20,773 - 137,319	128 - 256 kbps	Wallops, Hawaii, Dongara
Red	Pre Outbound Lunar Flyby	9 Oct 2018 11:56	13 Oct 2018 05:11	5,355	280,942 - 385,862	4 - 32 kbps	Hawaii, Wallops, Dongara, Hart.
Red	Outbound Lunar Flyby	13 Oct 2018 05:11	13 Oct 2018 15:11	600	370,207 - 401,505	4 - 32 kbps	Dongara, Hawaii, Hart.
Cyan	Earth Perigee	16 Oct 2018 17:11	17 Oct 2018 03:11	600	145,025 - 150,762	32 - 128kbps	Dongara, Hart., Wallops
Yellow	Outbound Crossing of Lunar Orbit	20 Oct 2018 17:11	21 Oct 2018 03:11	600	383,923 - 416,856	4 - 32 kbps	Hawaii, Wallops, Dongara, Hart.

Lunar IceCube Deployment Event from SLS



Deployment of Lunar IceCube from SLS



LunarIceCube

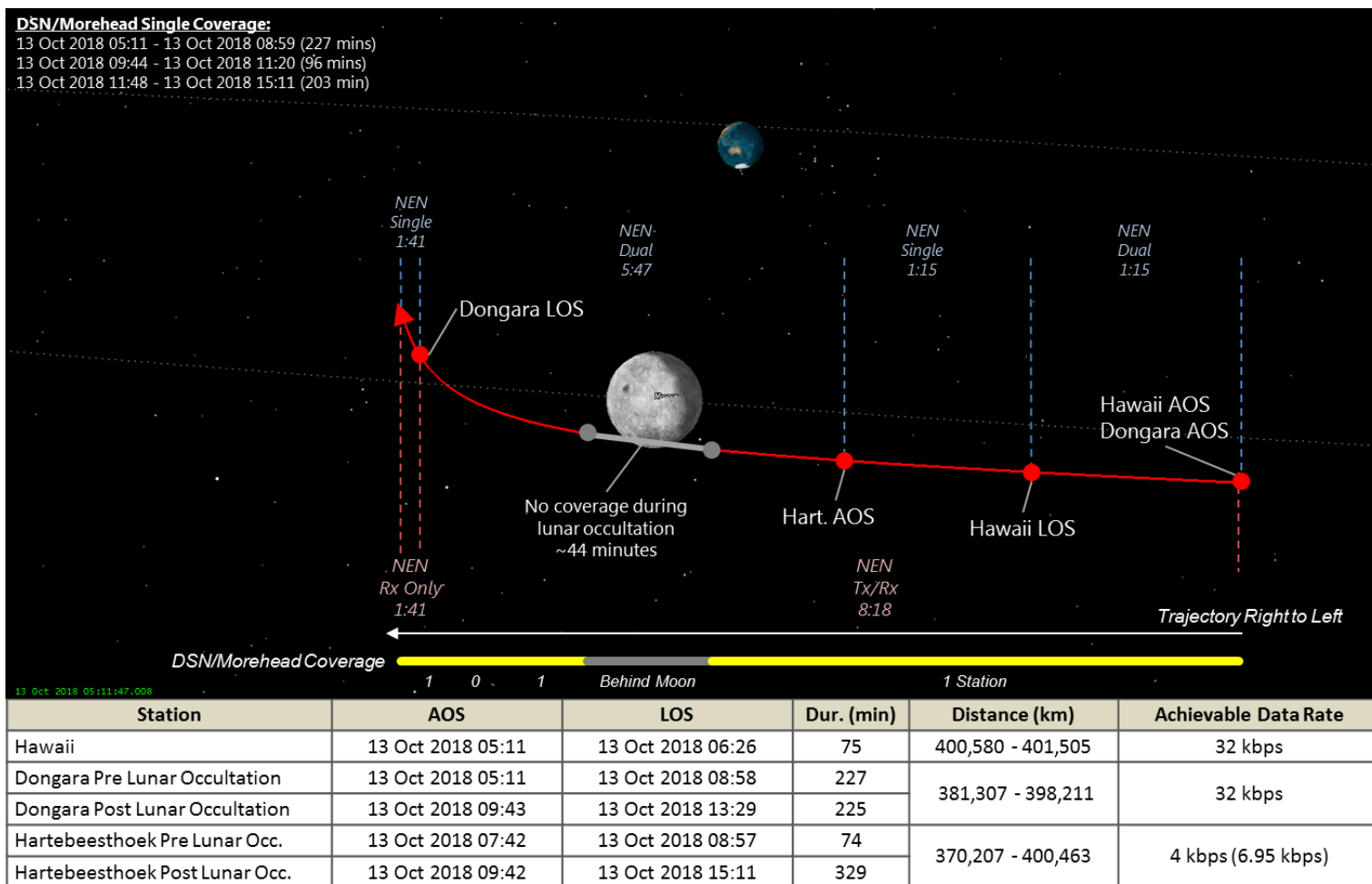
Wallops Coverage (128 kbps)

7 Oct 2018 15:39:56.961

Outbound Lunar Flyby (10 hour event)



Summary: This complete event has single DSN station coverage. Dongara and Hartebeesthoek could be used to provide support during the entire event, except during lunar occultation when Lunar IceCube will be out of contact.



CubeSat Flight Hardware Options for Lunar and L1/L2 missions

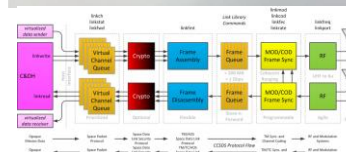
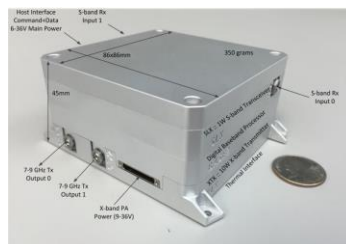


- **In addition to evaluating the NEN's ability to support EM-1 CubeSats that will utilize the IRIS Radio, the NEN performed a number of evaluations that may benefit future CubeSats:**
 - Developed CubeSat radio support requirements to achieve NEN compatibility to be provided to radio vendors
 - Identified alternative radios that may offer benefits
 - Identified a number of potential antennas for CubeSats to consider

Potential Radios for Lunar and L1/L2 CubeSats



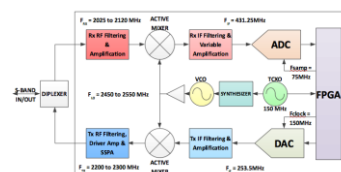
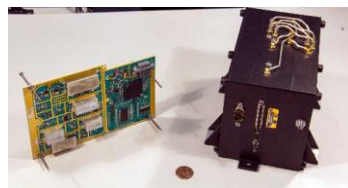
Innoflight® CubeSat S-Band Transceiver (SCR-100)



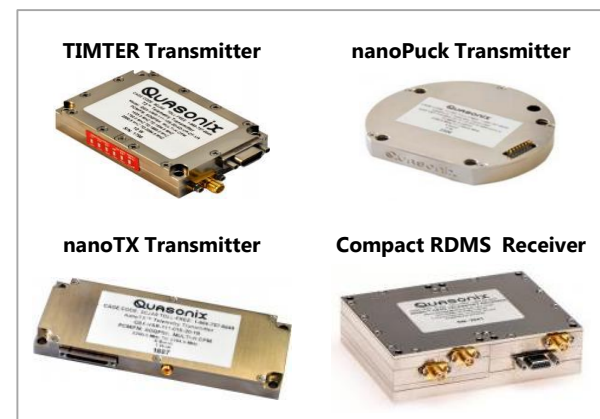
Tethers SWIFT® Software Defined Radios



Vulcan®

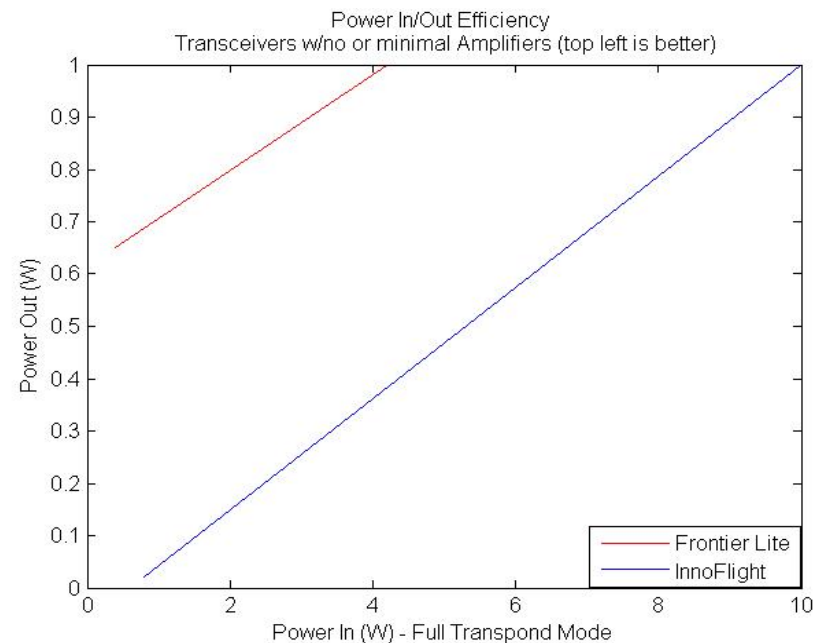
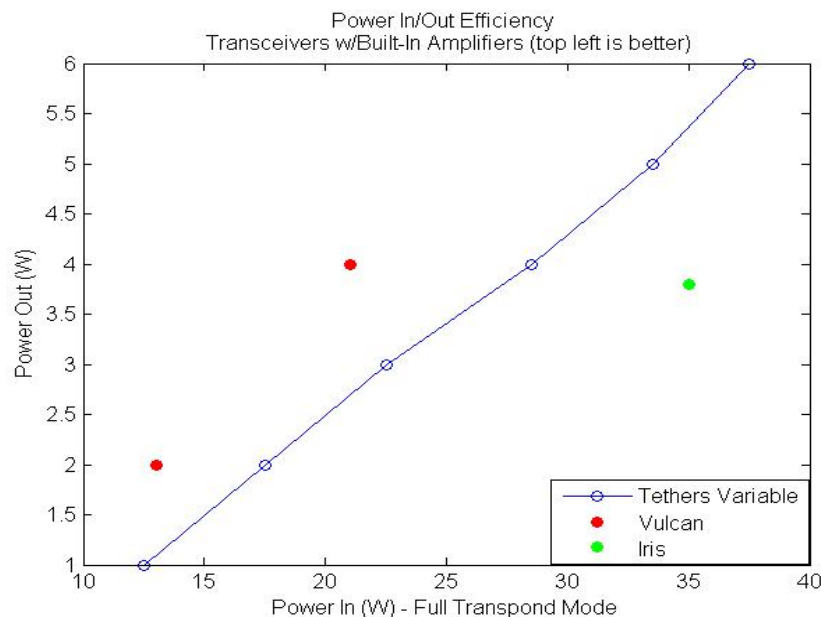


APL CORESAT® Frontier Radio Lite



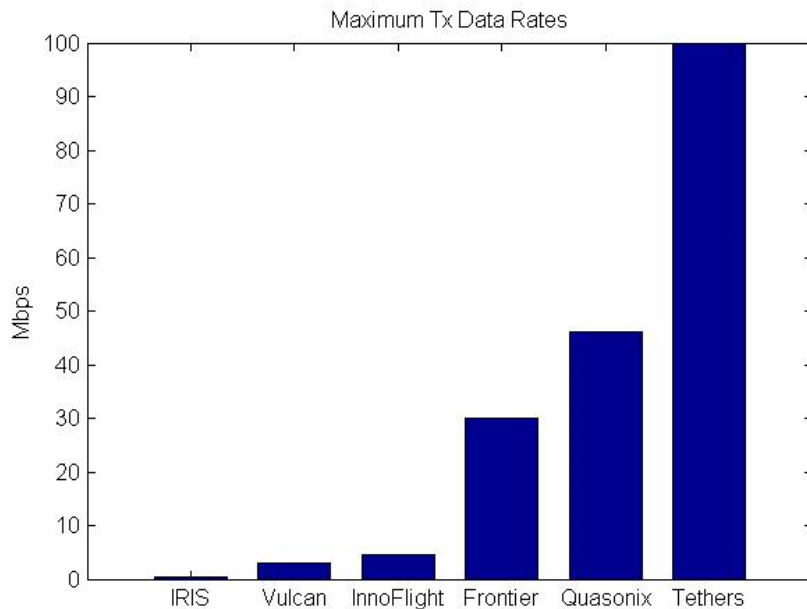
Quasonix®

Comparison of Key Differentiating Features – Power Efficiency

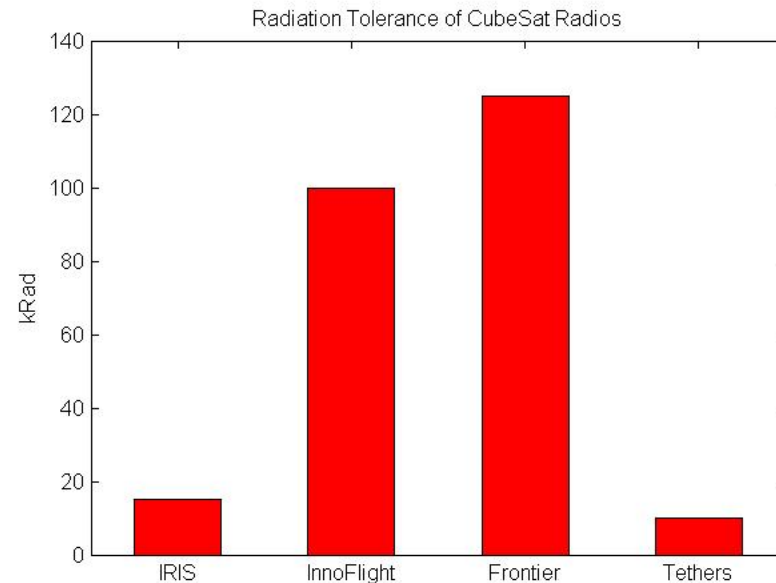


Comparison of Key Differentiating Features

– Data Rate, Radiation Tolerance



Note: Iris 256kbps tested; 8Mbps planned
Tethers w/QPSK=100Mbps; w/32APSK=300Mbps possible



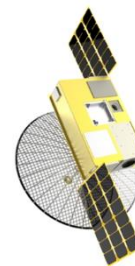
Note: Tethers 100kRad planned;
Vulcan not tested; Quasonix tested for LEO

NEN Evolution

- **NEN is ready today to support CubeSats**
- **Planned NEN expansions provide increased CubeSat support**
- **CubeSat radios and NEN receivers achieve high data rates for CubeSat missions over X, S and Ka-band**
- **NEN is capitalizing on Commercial Service Providers (CSP)/Academic Partnerships including small apertures, large apertures and X-Band uplink**
- **NEN is investigating streamlining mission planning and integration and test and scheduling activities**



NEN Wallops 11 Meter class antenna



NASA GSFC/Wallops LunarCube with deployable X-band antenna based on University of Colorado/Goddard X/S band CubeSat Radio and NEN

Conclusion



- After selection, no charge for pass supports for NASA missions using NASA-owned stations
- Mission Planning (e.g. RFICD, Coverage, Link Analysis, Loading Analysis), no charge prior to mission commitment
 - Mission Planning, Integration and Test (MPI&T) services after mission commitment are negotiable, function of risk versus cost
- Questions – contact Scott Schaire, scott.h.schaire@nasa.gov, 757-824-1120, NASA Goddard Space Flight Center, Near Earth Network Wallops Manager